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Air Resources Board

John D. Dunlap, III, Chairman
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Pete Wilson
Governor

October 1, 1998

TO: All Interested Parties:

SUBJECT: **PROPOSED REFUELING EMISSIONS INVENTORY**

The Air Resources Board (ARB) staff is in the process of updating the refueling emissions estimates of off-road mobile sources using a new model called OFFROAD. This document describes the details related to the various input factors and methodology used to estimate the refueling emissions inventory.

It is the practice of the ARB staff to present major emission inventory changes to the Board for its approval. As such, staff plans to take the refueling inventory to the Board in the spring of 1999.

As part of the public review process we have scheduled a workshop to solicit your comments and suggestions on the enclosed Proposed Refueling Emission Inventory. The workshop is scheduled as follows:

DATE: November 20, 1998
TIME: 10:00 a.m. to 3:00 p.m.
PLACE: Monitoring and Laboratory Division
Northgate Laboratory
600 North Market Boulevard (at Northgate Blvd.)
Sacramento, California 95834

If you believe the underlying assumptions used to develop the inventory can be improved, we will be happy to review any supporting data or information. Written comments can be submitted to Dean Bloudoff at the address listed on the letterhead. Comments can be submitted to Mr. Bloudoff by E-Mail at dbloudof@arb.ca.gov. We would appreciate receiving your comments no later than December 1, 1998.

We are developing a Refueling Emissions Inventory Mailing list. If you would like to continue receiving information on the Refueling Emissions Inventory, please complete the enclosed mailing list update form.

This facility is accessible to persons with disabilities. If accommodation is needed, please contact Elizabeth Mongar at (916) 263-1630 or TDD (916) 324-9531 or (800) 700-8326

for TDD calls outside the Sacramento area by November 12, 1998. Please call Elizabeth Mongar at (916) 263-1630 if you plan on attending so that we can assure adequate seating.

We appreciate your participation in our process. If you have questions or need clarifications, please call Dean Bloudoff at (916) 263-2070.

Sincerely,

William V. Loscutoff, Chief
Monitoring and Laboratory Division

Enclosures

cc: Bob Cross, MSCD

UPDATE TO PROPOSED REFUELING EMISSIONS INVENTORY MAILING LIST

NAME: _____

AFFILIATION: _____

ADDRESS: _____

PHONE: _____ FAX: _____

E - MAIL ADDRESS: _____

We are updating our mailing lists. If you are interested in remaining on our PROPOSED REFUELING EMISSIONS INVENTORY mailing list please take a moment to fill out and return this form (Please print clearly).
We will delete your name from our mailing list if we do not receive this mailing list form by October 30, 1998.

MAIL/FAX THIS FORM TO:

**Elizabeth Mongar
Engineering and Laboratory Branch
Air Resources Board
P.O. Box 2815
Sacramento, CA 95812**

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California Environmental Protection Agency

 **Air Resources Board**

DRAFT

Proposed Refueling Emission Inventory

October 1, 1998

Introduction

The purpose of this report is to provide an overview of the various input factors and methodology used to develop the refueling emissions inventory for off-road mobile sources. The off-road refueling emissions inventory includes estimates from the following equipment categories:

1. Agricultural
2. Airport Ground Support
3. Construction
4. Lawn and Garden
5. Light Duty Commercial
6. Light Duty Industrial
7. Logging
8. Pleasure Craft
9. Recreational
10. Transport Refrigeration Units

Refueling within these equipment categories is done predominantly with portable fuel containers, and to a lesser degree, dispensing facilities (service station or pump refueling). Often, refueling events using portable containers result in fuel spillage from over filling of equipment fuel tanks. Spillage can and does occur with these portable containers during transport and storage; portable containers are also a significant source of diurnal and resting losses. Both container and pump refueling can be directly associated with Hydrocarbon (HC) emissions from both spillage and vapor displacement.

Population and Activity

Statewide equipment populations and activity parameters such as usage in hrs/year, average maximum horsepower ratings, and load factors used in calculating the refueling emissions estimates are the same as those currently in the OFFROAD model. Two categories, Pleasure Craft and Large SI Engines, will be presented for Board approval later this year. For information on methodology and sources regarding these two categories please refer to Mobile Source Control (MSC) Division documents entitled “MSC 98-14 Pleasure Craft” and “MSC 98-11 Large SI Engines.” Any changes in these categories prior to final Board approval will be reflected in the refueling emissions estimates.

Refueling Events

There are two types of refueling events: pump refueling and portable container refueling. Refueling and evaporative emissions factors have been derived based on each type of refueling event. Refueling events are dependent on equipment and horsepower (hp) categories, as well as engine type. A complete definition of refueling events by equipment category are shown in Table 1.

Table 1
Refueling Event Definitions

Equipment Category	Hp Category	Engine Type	Refueling Event Type
Agricultural Airport Ground Support Construction Lawn & Garden Light Duty Commercial Light Duty Industrial Logging	ALL	2 Stroke	100 % Container Refueled
	≤ 25	4 Stroke	100 % Container Refueled
	> 25	4 Stroke	100 % Pump Refueled
Pleasure Craft (Excludes Personal Water Craft)	≤ 15	2/4 Stroke	100 % Container Refueled
	> 15	2/4 Stroke	100 % Pump Refueled
Personal Water Craft (PWC)	ALL	ALL	60% Container 40% Pump Refueled
Recreational	ALL	2 Stroke	100 % Container Refueled
	< 25	4 Stroke	100% Container Refueled
	≥ 25	4 Stroke	60% Container 40 % Pump Refueled
Transport Refrig. Units	ALL	ALL	100% Pump Refueled

As shown in Table 1, two equipment categories, PWC and Recreational, are best defined by a combination of both pump and container refueling. While it is generally accepted that equipment in these two categories receive some container refuelings, staff believes the number to be less than

100%. Therefore, a weighted average was selected of 60% container refueling and 40% pump refueling. This weighted average is based on fuel consumption rates, average tank volumes, and equipment activity. For example, a PWC can use approximately 40 gallons of fuel during 6 hours of continuous use. Based on a fuel tank size of 15 gallons and the assumption that only the first refueling is performed at the pump, the additional 25 gallons used must be delivered from a portable fuel container(s). This is representative of approximately 40% of the fuel used being delivered by the pump and 60% by portable container.

Where possible staff have selected the most conservative approach (lowest estimate) in estimating the container specific portions of the refueling emissions inventory (i.e., container transport/storage spillage, container diurnal). This is necessary because all calculations in these areas reflect the assumption that container populations are equal to equipment populations. Staff is aware that one portable refueling container may be used to perform refueling events on several individual pieces of equipment, justifying the conservative approach.

Refueling emission estimates are based on the assumption that all refuelings are fill-ups. Furthermore, all refueling emission estimates are calculated for gasoline fueled two and four stroke engines only.

Refueling Emission Components

Pump Refueling

There are two components of refueling emissions associated with pump refueling: (1) refueling spillage and (2) vapor displacement. Refueling spillage emissions are HC emissions that result from fuel spilled during the refueling event. Vapor displacement emissions are those HC emissions that result from displacing fuel vapors in the fuel tank with liquid fuel.

Container Refueling

There are five components of refueling emissions associated with container refueling: (1) refueling spillage, (2) vapor displacement, (3) container transport/storage spillage, (4) container diurnal losses, and (5) container resting losses. The first two, refueling spillage and vapor displacement, are as previously defined. Container transport/storage spillage emissions are HC emissions that result due to fuel spilled from the portable container during transport and while in storage. Container diurnal losses are HC emissions generated by the evaporation of liquid fuel from the vented portable container. Container resting losses are HC emissions generated by the permeation of fuel vapor while the portable container holds liquid fuel and vapors (significant only for plastic containers).

Emission Factors

Refueling Spillage Emission Factors

The average amount of fuel spilled during each refueling event is estimated at 3.6 grams/refuel for pump refueling, and 17 grams/refuel for portable container refueling. These estimates are based on data contained in the Nonroad Engine and Vehicle Emission Study (NEVES) report by the

U.S. Environmental Protection Agency (U.S.EPA). With the assumption that all refuelings are fill-ups, the amount of fuel spilled per gallon of gasoline consumed may be calculated by dividing the spillage event estimate (grams/refuel) by the equipment fuel tank volume (gallons/refuel) to calculate a spillage emission factor (grams/gallon consumed). Individual spillage emissions factors for each category are calculated as follows:

$$\text{Spillage EF}_{\text{pump}} \left[\frac{\text{g}}{\text{gal}} \right] = \frac{3.6}{\text{Tank Vol}} \left[\frac{\text{g}}{\frac{\text{gal}}{\text{refuel}}} \right]$$

$$\text{Spillage EF}_{\text{container}} \left[\frac{\text{g}}{\text{gal}} \right] = \frac{17.0}{\text{TankVol.}} \left[\frac{\text{g}}{\frac{\text{gal}}{\text{refuel}}} \right]$$

For equipment categories that are considered both container and pump refueled (see Table 1) a weighted average is calculated as follows:

$$[60\%] * 17 \text{ g/refuel}_{(\text{container})} + [40\%] * 3.6 \text{ g/refuel}_{(\text{pump})} = 11.64 \text{ g/refuel}_{\text{container/pump}}$$

Where 11.64 grams/refuel is considered the average amount of fuel spilled for the combined event. Thus, the combined event spillage emission factor for each category is calculated as follows:

$$\text{Spillage EF}_{\text{container/pump}} \left[\frac{\text{g}}{\text{gal}} \right] = \frac{11.64}{\text{TankVol.}} \left[\frac{\text{g}}{\frac{\text{gal}}{\text{refuel}}} \right]$$

Vapor Displacement Emission Factors

The pump dispensed refueling vapor displacement emission factor is 0.227 grams/gallon for Phase II vapor recovery systems as shown in Acurex Report FR-96-114, Table 5-41. Container dispensed refueling vapor displacement emission factors are calculated according to the

following equation shown in U. S. EPA NEVES Report:

$$\text{Disp.} = -5.909 + 0.0884 \times \text{Td} + 0.485 \times \text{RVP}$$

Where:

Disp.=	Displacement (grams/gallon)
Td =	Temperature of dispensed fuel (°F)
RVP =	Reid Vapor Pressure of fuel

Based on this equation using an average temperature of dispensed fuel of 75° and an RVP of 7.83, the container dispensed refueling vapor displacement emission factor is 4.52 grams/gallon. For equipment categories that are considered both container and pump refueled a weighted average is calculated as follows:

$$\text{Container/Pump Disp.} = [(60\%) \times 4.52 \text{ g/gal}_{\text{container}}] + [(40\%) \times 0.227 \text{ g/gal}_{\text{pump}}]$$

Based on this equation the container/pump dispensed refueling vapor displacement emission factor is 2.809 grams/gallon.

Container Transport/Storage Spillage Emission Factors

The average amount of fuel spilled from portable refueling containers during transport and storage is estimated at 18 grams/gallon of gasoline consumed. This estimate is based on data included in a report entitled, "OPEI/CAAC Spillage and Evaporative Hydrocarbon Losses for Lawn and Garden Applications" prepared by the Outdoor Power Equipment Institute (OPEI). The OPEI report separates container transport/storage spillage emission factors into two categories, commercial and consumer. In the report the emission factors for transport/storage spillage from portable containers is 9 grams/gallon for consumer applications, and 101 grams/gallon for commercial applications. While this division of equipment usage is easily defined in the Lawn and Garden category, the OFFROAD model contains several categories that cannot be segregated in this manner. Therefore, staff chose to use a weighted average to calculate a container transport/storage emission factor that could be applied to all categories in OFFROAD.

Using population data in California for the Lawn and Garden category, the ratio of consumer equipment verses commercial equipment is approximately 9 to 1. In the absence of data for the other categories in OFFROAD with respect to container spillage, staff used the OPEI data as a

surrogate for all categories to derive a universal container transport/storage spillage emission factor as follows:

$$\text{Container EF} = [9 \times (\text{9g/gal}_{\text{consumer}}) + 1 \times (\text{101g/gal}_{\text{commercial}})] / 10$$

where container EF is the container transport/storage emission factor given in grams/gallon of fuel consumed for all categories in OFFROAD that are considered container refueled. Based on this equation the container transport/storage emission factor is 18 grams/gallon. For equipment categories that are considered both container and pump refueled, a percentage of the container EF is calculated based on the refueling event definition.

Container Diurnal Loss Emission Factor

The container average diurnal mass loss rate is 1 gram/gallon/day as described in the report entitled "OPEI/CAAC Spillage and Evaporative Hydrocarbon Losses for Lawn and Garden Applications". Since State specific refueling container population data or average volume of stored fuel data are not available, staff determined a relationship between the average diurnal mass loss rates and equipment activity.

Diurnal losses are greatest when the portable container is left vented to the atmosphere (secondary vent open, open spout attached). To select the most conservative approach in calculating diurnal losses, staff made the assumption that portable containers are stored with secondary vents closed and spouts sealed, or removed and the portable containers capped. This implies that diurnal losses occur only when the portable containers are in use during refueling events which coincide with equipment use. Therefore, diurnal losses are directly related to equipment activity rates.

From anecdotal evidence staff selected a refueling container size of 2.5 gallons containing 2 gallons of liquid fuel to represent an average portable refueling container. Using the average diurnal loss rate of 1 gram/gallon/day provides us with the following equation:

$$2 \text{ gallon}_{(\text{liquid vol.})} \times 1 \text{ gram/gallon/day}_{(\text{avg. Diurnal loss rate})} = 2 \text{ grams/day}$$

where 2 grams/day is the average diurnal loss rate for a portable fuel container per day of equipment activity. To calculate a container diurnal loss emission factor in grams/year, the equipment activity is converted from hrs/year to days/years and multiplied by the average diurnal loss rate. This provides an equipment specific diurnal loss. Again, for equipment categories that are considered both container and pump refueled, a percentage of the container diurnal loss emission factor is calculated based on the refueling event definition.

Container Resting Loss Emission Factor

Resting loss emissions are not included in this report due to the lack of available data at this time.

However, these emissions may be significant. To determine the potential magnitude of these emissions the U.S. EPA NEVES report cites the amount of fuel a plastic storage container is permitted to lose and still meet the standards devised by the American Society for Testing and Materials (ASTM). A nonmetallic fuel container can pass the standards set by ASTM if it loses less than 1% of its mass over 30 days at a temperature of 75° F. This indicates the fuel container could lose as much as 28 grams of fuel a month.

Equipment Fuel Tank Volume

Estimates of equipment fuel tank volumes were derived from a report prepared for the ARB by Energy and Environmental Analysis (EEA) entitled, "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model" dated 1997. Where data were incomplete, staff supplemented fuel tank volume data from the U.S. EPA NEVES report, as well as the "OPEI/CAAC Spillage and Evaporative Hydrocarbon Losses for Lawn and Garden Applications" report by OPEI. A complete list of fuel tank volumes by equipment and hp category is shown in Attachment 1.

Methodology

OFFROAD generates a refueling emission inventory for HC pollutants by equipment type accounting for a given scenario year. The basic equation for OFFROAD is:

$$P_{I,y} = \sum_I [Pop_I * Emsfac_I * Hrs_I] + [CD EF * Pop_I]$$

where:

P	=	pollutant (grams/yr)
Pop	=	equipment population (# of units)
Emsfac	=	combined refueling emissions factors (grams/hr)
Hrs	=	annual average use (hours/year)
CD EF	=	container diurnal emission factor (grams/year)
y	=	scenario year (1970 - 2020)
I	=	equipment type

The combined refueling emissions factors (Emsfac) are calculated for each category using the following equation:

$$Emsfac = [\{bsfc * load * hp\} / density] * [Refuel EF + Vapor EF + Cont. EF]$$

where:

bsfc	=	brake specific fuel consumption (lb/Bhp-hr)
load	=	average load factor
hp	=	average horsepower (hp)
density	=	density of fuel (lb/gallon)
Refuel EF	=	Refueling spillage emission factor (g/gal)

Vapor EF = Displace vapor refueling emission factor (g/gal)
Cont. EF = Container Transport/Storage spillage emission factor (g/gal)

A complete list of all emission factors by category are shown in Attachment 1. Table 2 shows the statewide proposed refueling emission estimates in tons/day for CY 1990.

Table 2
1990 PROPOSED REFUELING EMISSIONS INVENTORY
(Statewide - Tons per Day)

Equipment Category	Fuel	HC
Agricultural	G4	1.213
Airport Ground	G4	0.006
Construction	G2	0.034
	G4	1.022
Lawn and Garden	G2	4.450
	G4	6.797
Light Duty Commercial	G2	0.208
	G4	4.189
Light Duty Industrial	G2	0.002
	G4	0.108
Logging	G2	0.309
	G4	0.837
Pleasure Craft	G2	1.590
	G4	0.114
Recreational	G2	10.125
	G4	4.180
Transport	G4	0.229
Total		35.412

G2 Gasoline - 2 stroke
G4 Gasoline - 4 stroke

ATTACHMENT 1

2265008050	Cargo Loader	G4	120	0.101	3.6	35.64	0.227	0.00	0.00	0.55	0.50	70	6.17	3.12	1.02	719	75
2265008055	Cart	G4	15	1.700	17	10.00	4.520	18.00	12.50	0.90	0.50	12	6.17	0.88	21.20	150	23
2265008060	Deicer	G4	120	0.076	3.6	47.37	0.227	0.00	0.00	0.55	0.95	93	6.17	7.88	2.39	22	32
2265008065	Forklift	G4	50	0.141	3.6	25.53	0.227	0.00	0.00	0.70	0.30	50	6.17	1.70	0.63	726	71
2265008070	Fuel Truck	G4	175	0.054	3.6	66.67	0.227	0.00	0.00	0.55	0.25	130	6.17	2.90	0.81	22	45
2265008075	Ground Power Unit	G4	175	0.047	3.6	76.60	0.227	0.00	0.00	0.55	0.75	150	6.17	10.03	2.75	796	57
2265008080	Lav Cart	G4	15	3.400	17	5.00	4.520	18.00	12.50	0.90	0.50	12	6.17	0.88	22.69	150	3
2265008085	Lav Truck	G4	175	0.086	3.6	42.01	0.227	0.00	0.00	0.55	0.25	130	6.17	2.90	0.91	1,212	63
2265008090	Lift	G4	120	0.071	3.6	50.70	0.227	0.00	0.00	0.55	0.50	100	6.17	4.46	1.33	376	119
2265008095	Maint. Truck	G4	175	0.054	3.6	66.67	0.227	0.00	0.00	0.55	0.50	130	6.17	5.79	1.63	449	83
2265008100	Other	G4	50	0.141	3.6	25.53	0.227	0.00	0.00	0.70	0.50	50	6.17	2.84	1.04	183	130
2265008105	Service Truck	G4	250	0.039	3.6	92.31	0.227	0.00	0.00	0.55	0.20	180	6.17	3.21	0.85	1,299	136
2265008110	Water Truck	G4	175	0.047	3.6	76.60	0.227	0.00	0.00	0.55	0.20	150	6.17	2.67	0.73	310	20
2265009005	Transport Refrigeration Units	G4	15	0.800	3.6	4.50	0.227	0.00	0.00	0.90	0.50	12	6.17	0.88	23.02	750	4,367
2282005010	Vessels w/Outboard Engines	82	2	12.140	17	1.40	4.520	18.00	11.17	1.30	0.00	0	6.17	0.00	0.00	134	3,004
2282005010	Vessels w/Outboard Engines	82	15	2.833	17	6.00	4.520	18.00	0.50	1.30	0.75	7	6.17	1.11	28.04	6	166,310
2282005010	Vessels w/Outboard Engines	82	25	0.353	3.6	10.20	0.227	0.00	0.00	1.30	0.75	20	6.17	3.16	1.83	17	45,193
2282005010	Vessels w/Outboard Engines	82	50	0.164	3.6	21.95	0.227	0.00	0.00	1.30	0.75	43	6.17	6.79	2.66	32	44,121
2282005010	Vessels w/Outboard Engines	82	120	0.078	3.6	46.15	0.227	0.00	0.00	1.30	0.75	90	6.17	14.22	4.34	148	38,797
2282005010	Vessels w/Outboard Engines	82	175	0.046	3.6	78.26	0.227	0.00	0.00	1.30	0.75	154	6.17	24.34	6.64	204	17,916
2282005010	Vessels w/Outboard Engines	82	250	0.032	3.6	112.50	0.227	0.00	0.00	1.30	0.75	221	6.17	34.92	9.05	266	5,144
2282005010	Vessels w/Outboard Engines	82	500	0.024	3.6	150.00	0.227	0.00	0.00	1.30	0.75	291	6.17	45.98	11.54	804	1,038
2282005025	Sailboat Auxiliary Outboard Engine	82	15	2.833	17	6.00	4.520	18.00	2.25	1.30	0.75	7	6.17	1.11	28.04	27	3,744
2282005025	Sailboat Auxiliary Outboard Engine	82	25	0.353	3.6	10.20	0.227	0.00	0.00	1.30	0.75	20	6.17	3.16	1.83	13	2,013
2282005025	Sailboat Auxiliary Outboard Engine	82	50	0.164	3.6	21.95	0.227	0.00	0.00	1.30	0.75	43	6.17	6.79	2.66	14	1,867
2282005030	Personal Water Craft	82	120	0.728	11.64	16.00	2.809	10.80	3.25	0.90	0.76	45	6.17	4.99	71.52	65	90,072
2282010005	Vessels w/Inboard Engines	82	250	0.036	3.6	100.00	0.227	0.00	0.00	0.55	0.75	206	6.17	13.77	3.62	227	45,557
2282010010	Vessels w/Outboard Engines	82	250	0.060	3.6	60.00	0.227	0.00	0.00	0.55	0.00	0	6.17	0.00	0.00	57	16,494
2282010020	Sailboat Auxiliary Inboard Engine	82	50	0.235	3.6	15.32	0.227	0.00	0.00	0.70	0.75	30	6.17	2.55	1.18	55	6,086
2282010035	Vessels w/Inboard/Outboard Engine	82	250	0.164	3.6	22.00	0.227	0.00	0.00	0.00	0.00	0	6.17	0.00	0.00	160	176,272
2282010040	Vessels w/Inboard Jet Engines	82	500	0.082	3.6	44.01	0.227	0.00	0.00	0.00	0.00	0	6.17	0.00	0.00	132	46,543